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Sustainability of the water footprint of the Spanish pork industry

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ABSTRACT

Around 92% of the humanity's footprint (WF) relates to the agricultural sector, and a considerable proportion of this is associated with animal farming. In Spain, the swine sector accounts for 11% of agricultural output in economic terms and makes substantial demands on freshwater resources. In this study we estimate the WF of the Spanish pig sector at an average 19.5 billion m^3/yr (82% green, 8% blue, 10% grey) over the period 2001–08. During this period the WF increased by 23%, due to growing exports. About half the water needed to produce concentrate feed comes from Spain, with the remaining 50% embodied in imported feedstock products. When comparing the blue and grey WFs of feed production in the source regions with indicators of water scarcity and water pollution, we find that most of the feed produced in Spain, unlike that imported, comes from watersheds where freshwater resources are overexploited. The evaluation of the WF of four different pig production systems shows that pigs raised in extensive systems have the largest WF per tonne of live animal. However, water pollution is a particular problem in industrial systems given the high geographical concentration of animals. The swine sector is one of the largest consumers of natural resources in Spain and should, therefore, be an important focal point in agricultural, environmental and water policies.

1. Introduction

Agriculture makes a major contribution to the water footprint (WF) of humanity and a very high percentage of this is directly or indirectly linked to the production chain of animal products (Mekonnen and Hoekstra, 2012). Feed is the main contributor to the WF of livestock (Schlink et al., 2010; Mekonnen and Hoekstra, 2012). During 2001–10, 40% of the cereals grown globally were used to feed animals (FAO, 2014). According to Gerbens-Leenes et al. (2010), a positive correlation exits between a country's socio-economic development and its consumption of livestock products. Future changes in consumption patterns in developing countries, such as China and Brazil, will include increased demand for animal products (Liu and Savenije, 2008). It has been predicted that freshwater will increase by 70% between 2000 and 2025 (Bruinsma, 2003), without taking into account the water required to produce feed and the potential pollution problems generated by waste disposal.

The swine sector is the largest contributor to global meat production, with almost 80 million tonne in 2008 (FAO, 2014). In Spain the pork industry is especially important, as it contributes 11% to agricultural output (MAGRAMA, 2013). Unlike in other developed countries, where most of the pork production is produced in industrial systems, extensive production also plays a significant role.

Extensive production in Spain is a traditional practice that specialises in the Iberian pig, which is highly valued, mainly for its hams and sausages. The Iberian pig is an autochthonous porcine variety in western and southern areas of the Iberian Peninsula. Its breeding is bound up with *dehesa* farming, an extensively or semi-extensively managed system with different livestock species kept in oak forests of varying density with ground cover of herbaceous species and sparse shrubs (Rodriguez-Estevez et al., 2009; Hadjikoumis, 2012).

However, industrial production accounted for 91% of the 25.8 million animals in 2008, with Iberian pig stockbreeding making up only 9% (MAGRAMA, 2013). No more than a quarter of these animals were kept under free- or semi-free-range conditions, while the majority was fattened with concentrate feed (MAGRAMA, 2011).

The purpose of this study is to quantify and evaluate the green, blue and grey WF of Spanish pork production for the period 2001–08. A differentiation has been made between industrial and

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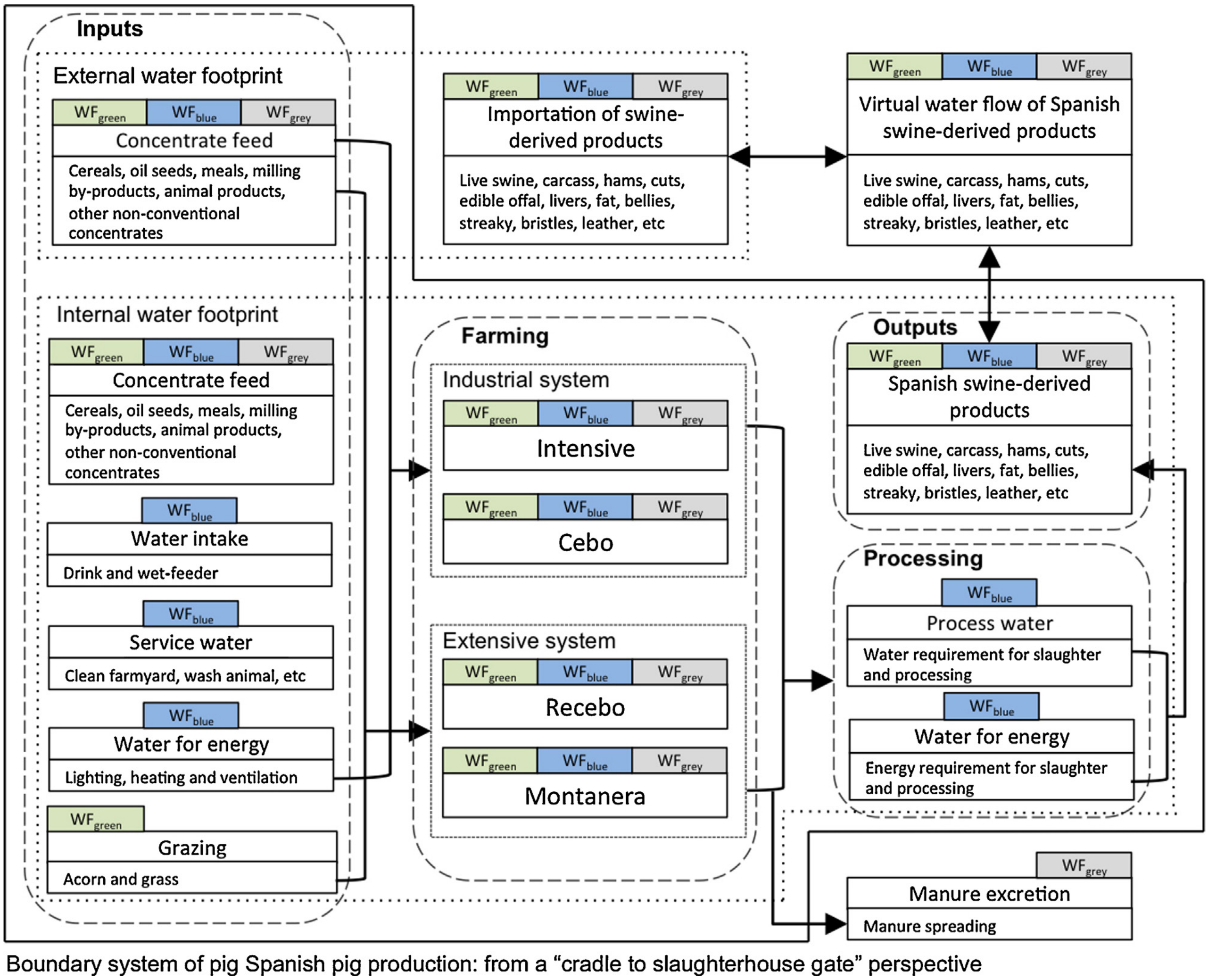

Fig. 1. System boundaries and WF components of the Spanish pork industry.

extensive farming. Since the Spanish swine sector is strongly embedded in an international trade context, and bearing in mind that feed production heavily contributes to the sector's overall WF, we assess the environmental sustainability of the WF associated with animal feeds by comparing the blue and grey components of the WFs in the supplying river basins with blue water scarcity and water pollution levels in those basins.

2. Material and methods

The WF is an indicator of human freshwater appropriation, defined as the total freshwater consumed or polluted, either directly or indirectly, to produce all the goods and services consumed by individuals, communities or industrial sectors (Hoekstra et al., 2011). In a globalised context, the trade of goods that require water inputs in production also entails a virtual water exchange (Allan, 1998).

In order to calculate the WF of the Spanish pork industry, we applied the framework for national WF accounting proposed by the Water Footprint Network (WFN) (Hoekstra et al., 2011). A distinction was made between three different components: the blue WF (consumption of water from surface and groundwater); the green WF (evapotranspiration of rainwater from the field); and the grey WF (the volume of freshwater required to assimilate the pollution load). ISO's WF standard (2014) allows for other methods, based on life cycle assessment (LCA) for products, but we focus here on a geographic WF analysis rather than on the WF of a product, which makes the WFN approach most suitable.

The analysis was conducted from a life cycle perspective, including water consumption and pollution of the most relevant processes in the production chain of pork, from feed production to slaughterhouse (Fig. 1). Some processes associated with pig production, such as constructing infrastructures and transportation of feed and live animals, contribute very little to the sector's overall WF, which justifies excluding them from the study (Hoekstra et al., 2011; Ercin et al., 2012).

Spanish pork production can be grouped into four systems (MAPA, 2007): the *intensive* farming system (an industrial system using White pigs); the *cebo* farming system (an industrial system using Iberian pigs); and the *recebo* and *montanera* farming systems (both extensive systems using Iberian pigs). In the *recebo* system, animals are fed outdoors and exclusively consume grazing products (mainly acorns and grass), with a minimum weight gain of 29 kg in 60 days of *dehesa* grazing. The *montanera* system is similar but the minimum weight gain is 46 kg. Regardless of farming system, most Iberian pigs are fed concentrate during the first months of their life.

Table 1
Growth and reproductive parameters for Spanish swine production.

Farming system	Intensive system		Extensive system	
	White pig *Intensive*[1–3]	Iberian pig *Cebo*[4–7]	Iberian pig *Recebo*[4–8]	Iberian pig *Montanera*[4–8]
Slaughter age (days)	210	270	475	455
Slaughter weight (kg of live animal)	105	145	151	151
Concentrate feed intake (kg per animal)	250	570	565	490
Grazing (kg acorn and grass per animal)	–	–	386	618
Feed conversion ratio for fattening pigs (kg feed per kg live weight)[a]	2.4	3.9	6.3	7.3
Feed conversion ratio for suckling pigs (kg feed per kg live weight)	1.6	1.1	1.1	1.1
Number of piglets per sow per year	23	14	13	13

Sources: [1]Hoque et al. (2009), [2]Hyun et al. (1997), [3]GENCAT (2011), [4]Barba et al. (2002), [5]Conde-Aguilera et al. (2011), [6]Criado et al. (2009), [7]Rueda (2007), [8]Rodriguez-Estevez et al. (2009, 2011).

[a] Conversion index includes natural products intake for free-range.

2.1. *Evaluating the water footprint of feed*

2.1.1. *Feed volume*

The total annual volume of feed consumed by the sector was estimated according to Hendry et al. (1995) and Mekonnen and Hoekstra (2012), where annual feed consumption is gauged from the total country carcass production and the feed conversion ratio (FCR). Since the number of live animals exported to be slaughtered in neighbouring countries is significant, around 1.1 million animals in 2002 (Lence, 2007), the feed consumption of these is included. Two categories of slaughtered animals were defined: suckling and fattening pigs (Table 1). Additionally, the annual volume of feed supplied for breeding (sows and boars) was also estimated by multiplying the number of sows and boars by the annual feed consumption per animal (see SI-A).

In the case of extensive management, in the first few months, and up to a size close to 60 kg, animals are fed with concentrate in semi-confinement areas (*cria* and *recria*). After this, animals are reared in semi-free-range on grass and concentrate, until they reach 105 kg (pre-*montanera*). Finally, they are kept under extensive farming conditions and feed on acorns, forage and other natural products (*montanera*).

2.1.2. *Feed composition*

Four different diets were defined according to the animal stages: starter, weaner, growing-finishing and sows. Statistical information of concentrate feed production in Catalonia (NE Spain) for the period 2005–09 (GENCAT, 2011) was used to estimate the feed composition of the major feedstock categories (see SI-B). Subsequently, major feedstock categories were broken down into specific crops and secondary products according to the ratio of the availability in the Spanish market of each crop per category. An annual balance was calculated to define the Spanish feedstock of each crop or secondary product, using the national production and import-export volumes (MITC, 2011; MAGRAMA, 2013).

2.1.3. *Water footprint of feed*

The ratios of the volumes of imported feed to those of domestically produced feed were used as a basis to estimate the origin of feed. Green, blue and grey WF estimates for imported crops and derived products were taken from Mekonnen and Hoekstra (2011), who estimated the WF of crop production and secondary products by applying a global crop water use model with a 5 by 5 arc minute spatial resolution. The grey WF estimates focused exclusively on the impacts of nitrogen applied as fertiliser in feed crop production.

2.1.4. *Water footprint of the* dehesa *grazing products*

Although free-ranging animals feed on a wide variety of natural products, acorn and grass can be considered the main feed components (Rodriguez-Estevez et al., 2009). We assume that a *dehesa* system is a mixture of grazing land (80% of the total surface) and open forests of holm oak and cork oak. The WF of pastures was computed according to the method described in Hoekstra et al. (2011), while using the CROPWAT model (FAO, 2010) for conventional crops. Since no crop coefficients for holm oak or cork oak are reported in the literature, we adopted the methodology proposed by Zhang et al. (2001) to estimate annual forest evapotranspiration (Eq. (1)):

$$\frac{ET}{P} = \frac{1 + w \times (ET_0/P)}{(1 + w \times (ET_0/P)) + (ET_0/P)^{-1}} \quad (1)$$

where ET is the actual evapotranspiration rate (mm/year), ET_0 the potential evapotranspiration (mm/year) and P the annual precipitation (mm/year). Coefficient w is the equivalent of the crop coefficient (Allen et al., 1998). Values were extracted from Willaarts et al. (2012). Calculations were done on a regional scale. Climatic data were extracted from weather stations located in the *dehesa* areas (AEMET, 2011).

As not all the water taken up by trees can be attributed to acorn production, the methodology of the value and product fractions proposed by Hoekstra et al. (2011) was followed. This allowed us to distribute the WF of a primary product to secondary products according to their yield (product fraction pf) and economic value (value fraction vf). We evaluated only the derived products with a direct market value, such as acorns, wood or cork. The environmental services provided by the forest were not included due to the difficulty of estimating their specific economic value (see SI-C).

Table 2
Input data for the production of one live animal (MAPYA, 2006).

	Suckling pig	Fattening pig	Sows
Drinking (L/animal/day)	3	13	22
Cleaning and services (L/animal/day)	0.35	0.6	0.6
Energy consumption (kwh/animal/day)	0.33	0.06	1.7

2.2. *Water footprint related to drinking, services and energy*

All the animal's drinking water, the water consumed with the wet-feeder, the water used to clean farmyards and to wash an animal and the water needed to produce the energy used in the farm during the animal's lifetime were also considered (Table 2). For extensive production, no service or energy requirements were included when animals were managed as free-range.

Regarding the WF of energy consumption, the values proposed by Hardy and Garrido (2010) were taken. Fuel oil, diesel and natural gas were considered to be the main sources for thermal energy and the Spanish electric mix for electricity (see SI-D).

Table 3
Input data for the estimation of the grey WF of pig slurry application.

Variable	Acronym	Value	Reference
Application rate (kg N/ha yr)	Appl	170	EEC (1991)
Leaching-runoff fraction	α	10	Hoekstra et al. (2011)
Maximum allowed concentration of nitrogen (mg/L)	C_{max}	11.29	EEC (1991)
Natural concentration of nitrogen (mg/L)[a]	C_{nat}	0.5	Liu et al. (2012)
Ammonia volatilisation coefficient (%)	–	44.6	MAPYA (2006)

[a] Natural transport of nutrient with non-anthropogenic causes.

2.3. Water footprint and virtual water flows related to pork products

The WFs of 21 secondary products were quantified according to the above-mentioned value and product fraction methodology, including the WF of the energy used in the slaughterhouse. The parameters vf and pf and the process water requirement were taken from Mekonnen and Hoekstra (2012) and the slaughterhouse's energy consumption from MAPYA (2005) (see SI-D).

Additionally, import and export volumes for the 21 swine-derived products were used to estimate the virtual water flows embodied in internationally traded pork products (MITC, 2011). The WFs of the pig products imported from foreign countries were taken from Mekonnen and Hoekstra (2012).

2.4. Environmental sustainability assessment of the water footprint of feed

In order to assess whether the WFs relating to feed are sustainable, we identified the blue water scarcity (BWS) and the water pollution level (WPL) for each river basin from which part of the Spanish pig feed originates. The first is defined as the ratio of the total blue WF to the blue water availability within a certain period (Hoekstra et al., 2012) and the second one as the ratio of the grey WF to the actual basin discharge. Since trade information is specified nationally, virtual water import volumes were downscaled to the river basin level based on the production patterns in the source countries, as given by Mekonnen and Hoekstra (2012). Subsequently, the hotspot watersheds were identified, i.e. river basins in which BWS or WPL exceeded 1 during at least part of the year. We used the monthly BWS data from Hoekstra et al. (2012), which cover the major river basins around the world and identify the number of months during which BWS is moderate, significant or severe. Data on WPL in relation to nitrogen were taken from Liu et al. (2012).

2.5. Grey water footprint of pig slurry applied as a fertiliser

Additionally, a preliminary assessment of the grey WF of the swine sector's nitrogen surplus was carried out by assuming that the direct use of pig manure as a fertiliser is the most common slurry management system in Spain (Penuelas et al., 2009). The grey WF of pig slurry ($WF_{grey\ pig\ slurry}$), i.e. the total freshwater volume required to assimilate nitrogen that leaches to groundwater or runs off to surface water, was calculated according to the methodology proposed by Hoekstra et al. (2011) (Eq. (2)) and based on data shown in Table 3.

$$WF_{grey\ pig\ slurry} = \frac{\alpha \times Appl}{C_{max} - C_{nat}} \quad (2)$$

The coefficients for nitrogen production from OECD (2011) were considered to estimate the total volume of nitrogen excreted by the swine sector. The analysis was developed on a regional scale. Due to the high cost of pig slurry transport (Iguácel and Yagüe, 2007), we assume that all the nitrogen excreted by pigs in a region is applied as fertiliser in the same region. In extensive management, it was assumed that the pig slurry produced when animals live under free- or semi-free-range conditions is assimilated by the ecosystem.

It should be noted that data on the grey WF of pig slurry are presented separately from the grey WF of feed production for pigs, in order to avoid double counting. Some overlap exists, because part of the nitrogen excreted by the swine sector is used as a fertiliser in the national production of feed.

3. Results

3.1. An overview of the water footprint of the Spanish swine sector

With a total carcass production of around 3.2 million tonne/yr, the WF of the Spanish swine sector averaged 19,517 Mm^3/yr during the period 2001–08 (82% green, 8% blue, 10% grey). Within the period a gradual increase was observed, with a value 23% higher in 2008 than in 2001 (21,576 Mm^3/yr versus 17,491 Mm^3/yr) (Fig. 2). Virtual water export increased by 2700 Mm^3/yr during the study period, while domestic pig product consumption remained constant. Most of the water consumed or polluted by the Spanish swine sector corresponded to indirect water requirements for feed production (99%). Only 170 Mm^3/yr of blue water was used for drinking by the animals and on-farm services, for the preparation of wet-feeders, for slaughterhouse use and for the production of the energy used by the sector (64%, 8%, 24% and 4% of blue water, respectively). The green water incorporated in grazing products was estimated to be around 490 Mm^3/yr (see SI-F).

Most of the WF relates to industrial systems, with a total WF of 15,550 Mm^3/yr for *intensive* farms and 2308 Mm^3/yr for the *cebo* system (82% green, 7% blue, and 11% grey for both). The WFs of the *recebo* and *montanera* systems were 159 (88% green, 5% blue, 7% grey) and 1500 Mm^3/yr (90% green, 4% blue, 6% grey), respectively.

With a virtual water balance of 3900 Mm^3/yr, Spain is a net exporter of virtual water associated with the pig sector (Fig. 2). Most exports (95%) remain within Europe, with Portugal, France, Germany, Italy and Russia receiving more than 80% of the total. According to the type of products, fresh and frozen meats accounted for 60% of the total water exported. Furthermore, more than 1.1 million fattened live animals were exported to other countries, such as Portugal, France and Italy, which is equivalent to a virtual water export of 500 Mm^3 per year.

3.2. Sustainability of the water footprint of Spanish pig feed

The global WF of Spanish swine feeds is spread worldwide because of the import of feed (Fig. 3). Almost half of the WF of Spanish pig feed is within Spain (8844 Mm^3/yr; 83% green, 7% blue and 10% grey), while the other half lies abroad (9973 Mm^3/yr; 92.5% green, 2.5% blue and 5% grey). As most of the imported crops come from relatively humid areas, green water is the main component of their WF. In contrast, Spanish feed has large blue and grey components due to the high irrigation rate in Spain.

As mentioned above, most of the blue WF of the Spanish swine sector lies within Spain. Given the great water scarcity in many

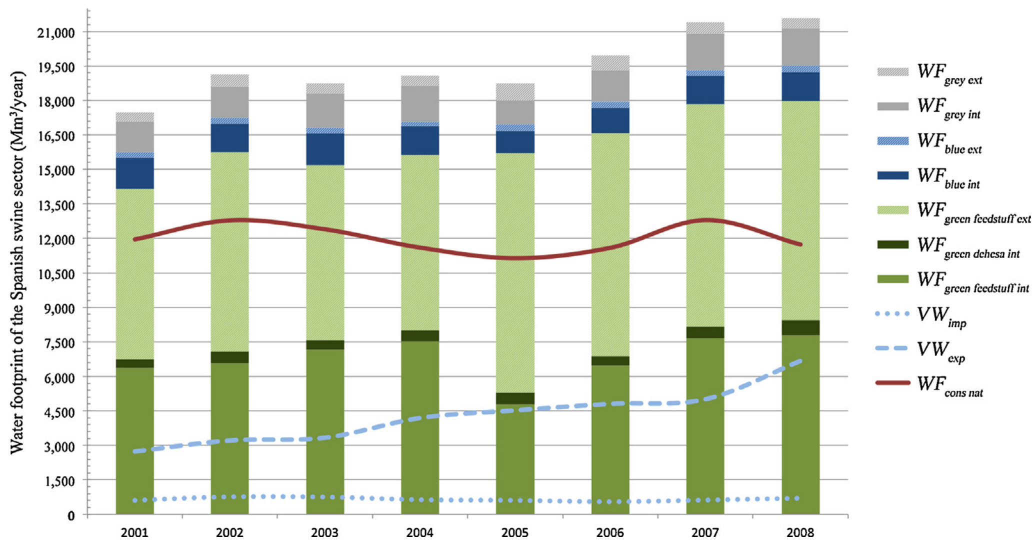

Fig. 2. The green, blue and grey WFs (WF_{Green}, WF_{Blue} and WF_{Grey}) of swine production in Spain according to its origin (internal or external and feedstuff or *dehesa* products), and the virtual water imported and exported (VW_{imp} and VW_{exp}) in relation to international trade in pork products. $WF_{cons\ nat}$ is the WF of Spanish pig consumption.

parts of Spain, the unsustainable hotspots of the blue WF related to Spanish pig feed are within Spain itself. The Ebro, Guadalquivir, Douro, Guadiana and Tagus river basins are the main hotspots, all of which are subject to severe water scarcity (Table 4). Cereal cropping in the river basins of southeast Spain, particularly those of the Guadiana and Guadalquivir, requires more attention because water scarcity in these basins is severe (BWS > 2) and the blue water volume consumed in this region constitutes more than 25% of the total blue WF of pig feed. In international terms, the import of maize and sunflower seed from the Portuguese side of the Guadiana and Tagus river basins and of sugar cane and molasses sugarcane from the river basins of the Indus (Pakistan and India), Ganges (India) and Nile (Egypt) is unsustainable, despite the low volume (blue WF less than 30 Mm^3/yr).

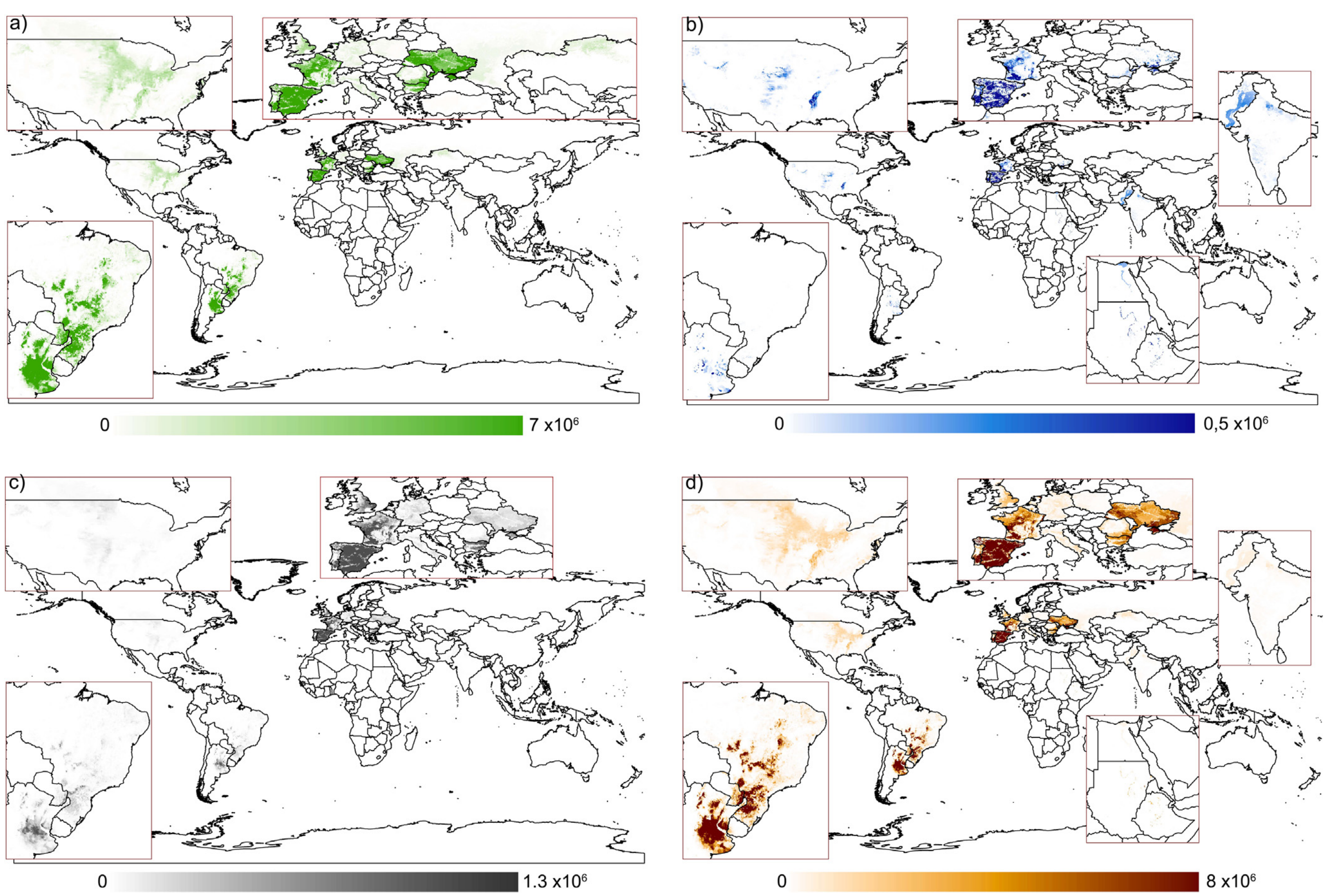

Fig. 3. The global WF of feed consumed by the Spanish swine sector; (a) green; (b) blue; (c) grey and (d) total WF. Average values for the period 2001–08 in m^3/pixel.

Table 4
The blue, grey and green WF of Spanish swine feeding in different river basins in the world, and the BWS and WPL per basin. Average values for 2001–2008. Presented data correspond with the most important watersheds from which feed is obtained. A full summary of this data can be found in the Supporting Information (see SI-H).

Major river basin	WF_{blue}		WF_{grey}		WF_{green}		BWS[a]	WPL[b]	Major contributing products
	Mm^3/yr	% WF_{feed}	Mm^3/yr	% WF_{feed}	Mm^3/yr	% WF_{feed}	Hoekstra et al. (2012)	Liu et al. (2012)	
Ebro	223.2	16.98	347.7	19.40	1638.5	10.70	0.83	1.37	Maize & barley
Guadalquivir	219.2	16.68	164.7	9.19	756.4	4.94	2.38	2.46	Maize & sunflower seed
Douro	219.7	16.72	467.3	26.07	2049.5	13.38	1.01	1.39	Maize, barley & sugar beet
Guadiana	253.1	19.25	193.5	10.80	942.4	6.15	2.49	1.69	Maize, sunflower seed & barley
Tagus	81.3	6.19	85.9	4.80	596.7	3.90	1.23	1.39	Maize & sunflower seed
Júcar	66.0	5.02	84.9	4.73	382.9	2.50	–	4.8	Maize
Segura	35.1	3.0	24.5	1.3	128.1	0.9	–	22.7	Maize
Mississippi	27.1	2.07	18.7	1.05	468.0	3.06	0.67	1.34	Soya bean & wheat
Indus	22.3	1.70	2.8	0.16	9.0	0.06	2.71	2.51	Sugar cane
Andalusian W.	30.9	2.35	36.7	2.05	169.8	1.11	–	22	Maize, barley & sunflower seed
Garonne	15.2	1.16	24.2	1.35	86.9	0.57	0.55	1.97	Maize
Loire	9.1	0.69	29.1	1.63	147.0	0.96	0.42	2.14	Maize
Parana	6.4	0.48	58.5	3.27	3556.0	23.22	0.05	1.13	Soya bean & wheat
Nile	9.4	0.72	0.6	0.03	3.0	0.02	0.85	0.06	Sugar cane
Rône	4.2	0.32	11.2	0.63	56.7	0.37	0.09	1.48	Maize
Ganges	5.5	0.42	0.7	0.04	4.5	0.03	2.41	3.79	Sugar cane
Rhine	2.1	0.16	34.9	1.94	108.0	0.70	0.11	2.54	Maize
Seine	3.6	0.28	15.5	0.86	113.9	0.74	0.83	3.78	Maize
Danube	4.4	0.33	19.3	1.07	189.4	1.24	0.11	1.49	Wheat & sunflower seed
Dniepr	3.5	0.27	18.8	1.05	454.7	2.97	0.9	1.52	Soya bean & wheat
Salado	2.0	0.16	19.9	1.11	846.4	5.53	0.64	1.09	Maize & soya bean

[a] Annual average monthly blue water scarcity, with monthly scarcity defined as the total blue WF in the catchment in a month divided by blue water availability in that month.
[b] Water pollution level, defined as total annual grey WF in the catchment divided by annual available assimilation capacity.

The grey WF of pig feed for the Spanish swine sector is located mainly in watersheds with a high water pollution level (WPL > 1) (Table 4). The Guadiana and Guadalquivir river basins are the most prominent hotspots, with a WPL of 1.7 and 2.5 respectively; they contribute about 18% of the total grey WF of pig feed. Maize in the upper Júcar basin is another hotspot, as 4.5% of the grey WF of Spanish pig feed is located there and the WPL is 4.8. Regarding foreign basins, the grey WF of cereal production in the European watersheds of the Rhine, Loire, Garonne, Rodin, Dnieper and Shine, with WPLs above 1.5, are identified as hotspots (Table 4). The import of soya beans from the Parana and Mississippi river basins, with a WPL of more than 1.1, should also be considered.

3.3. Distribution of the water footprint of pigs within Spain

Fig. 4 shows the areas of Spain with high pig production: NE Spain, between Catalonia and Aragon, which encompasses almost 45% of the total; NW Spain; the centre and south of Castile and Leon, mainly in the Ávila and Valladolid regions; NW of Castile-La Mancha, in the Toledo region; SE Spain, chiefly Murcia; and SW Spain, where most of the extensive systems are located. Throughout the study period, the WF in the majority of these regions increased, in Catalonia by almost 50%.

The grey WF of the 275,000 tonne/yr of nitrogen excreted was estimated at 1350 Mm^3. Most of this (97%) relates to industrial farming (see SI-J). As shown in Fig. 5a, seven districts had, on average, a nitrogen excretion rate of over 150 kg per hectare of agrarian surface, due to the high concentration of industrial farms. Fig. 5b shows the spatial distribution of the grey WF resulting from pig slurry applied as a fertiliser, and how some of the areas with a large grey WF overlap with areas classified as nitrate-vulnerable (groundwater bodies with a nitrogen concentration above 50 mg/l).

3.4. Water footprint of a pig in Spain

The average WF of a pig in Spain is estimated at 3765 m^3/tonne (83% green, 7% blue, 10% grey). Large differences were found between the different production systems. While an animal reared in an industrial system uses 3428 m^3/tonne (82.3% green, 7.5% blue and 10.2% grey) in the *intensive* system and 5619 m^3/tonne (82.5% green, 7.3% blue and 10.2% grey) in the *cebo* system, the volume of water needed for a free-ranging animal is 7507 m^3/tonne (87.4% green, 5.4% blue and 7.2% grey) under *recebo* conditions and 8111 m^3/tonne (89.9% green, 4.3% blue and 5.8% grey) under *montanera* conditions. The values for the 21 evaluated pork products are presented in the Supporting Information (SI-I). It should be emphasised that the grey WF figures reported here refer to the grey WF of a pig as a result of nitrogen fertiliser leaching in feed crop production. If the grey WF of pig slurry is considered, the figures change significantly, with a grey WF of pig slurry of 375 m^3/tonne in the *cebo* system, 229 m^3/tonne in the *intensive* system and 166 and 143 m^3/tonne in respectively the *recebo* and *montanera* systems (Table 5).

Table 5
The green, blue and grey WF of a live pig in Spain, in relation to the management system.

	Industrial systems		Extensive systems	
	Intensive (m^3/t)	*Cebo* (m^3/t)	*Recebo* (m^3/t)	*Montanera* (m^3/t)
$WF_{green\ feedstuff}$	2822	4635	4377	3786
$WF_{green\ grazing}$	–	–	2184	3504
$WF_{blue\ feedstuff}$	235	387	365	316
$WF_{blue\ drink\ \&\ service}$	20	21	36	34
$WF_{blue\ energy}$	0.3	0.3	0.4	0.4
$WF_{grey\ feedstuff}$	351	576	545	471
$WF_{grey\ pig\ slurry}$	143	166	375	229

4. Discussion

4.1. Water footprint implications

The substantial increase in pig production in the last 20 years, in combination with the sector's high specialisation characterised by a vertical integration between processors and producers, has led to significant feed imports. According to Galloway et al. (2007), trade liberalisation and improvements in transport infrastructures have resulted in a rise in the global feed trade, based on

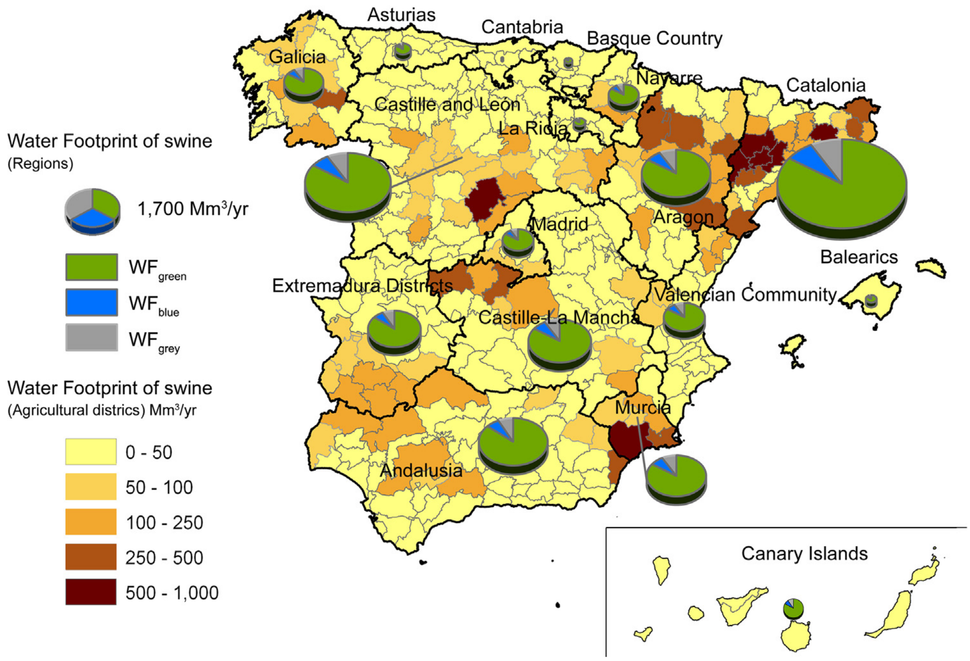

Fig. 4. The green, blue and grey WFs of Spanish swine per region and agricultural district.

least-cost decisions in international markets. By importing virtual water embodied in feed, Spain is saving the amount of water required to produce this feed, which lowers the pressure on national freshwater resources. In fact, Spain is country with the largest irrigated area in Europe, almost one third of the total (Lopez-Gunn et al., 2012), which translates into a big blue and grey WFs for the crops intended for animal feed.

Although more than 50% of the WF of pig feed is outsourced already, the environmental sustainability analysis shows that feed production in Spanish watersheds remains the main hotspot. The indirect water consumption of this sector is related to specific environmental impacts such as the water depletion in the Tablas de Daimiel National Park in the upper Guadiana river basin, due to intensive groundwater use to irrigate maize and winter cereals, inter alia (Fornes et al., 2000; Aldaya et al., 2010b)

The import of virtual water means water consumption and pollution occur at locations where crops are grown. Since most imported feeds come from areas with a high green water component, the pressure on freshwater resources is limited. Water quality degradation is still one of the most important externalities (Aldaya et al., 2010a). As Van Der Werf et al. (2005) found, nitrogen compounds are one of the biggest risks associated with feed production in western Europe. This concern is illustrated in the grey WF analysis, which shows that most imported cereals come from areas with a high WPL, notably European countries.

The significant increase in pork production in Spain in recent years, paired with the geographical concentration of farms, has contributed to local water pollution from excessive manure. There is a strong correlation between livestock density and nitrogen surplus per hectares (Penuelas et al., 2009). For instance, the area of nitrate-vulnerable zones in Catalonia has expanded from 370,000 hectares in 1998 to more than 1,000,000 in 2009, which is related to increased swine manure disposal (GENCAT, 2009).

Knowing the WF of the Spanish livestock sector can help the industry and the government to introduce criteria for sustainable production, to avoid imports from overexploited or polluted watersheds either within or outside Spain. The fact that livestock farmers are not big direct water users means that they do not receive much attention in water policies. As Hoekstra (2014) has pointed out, no national water plan in the world incorporates the fact that livestock is one of the most important (indirect) drivers of water consumption or pollution. It would be advisable to reconsider

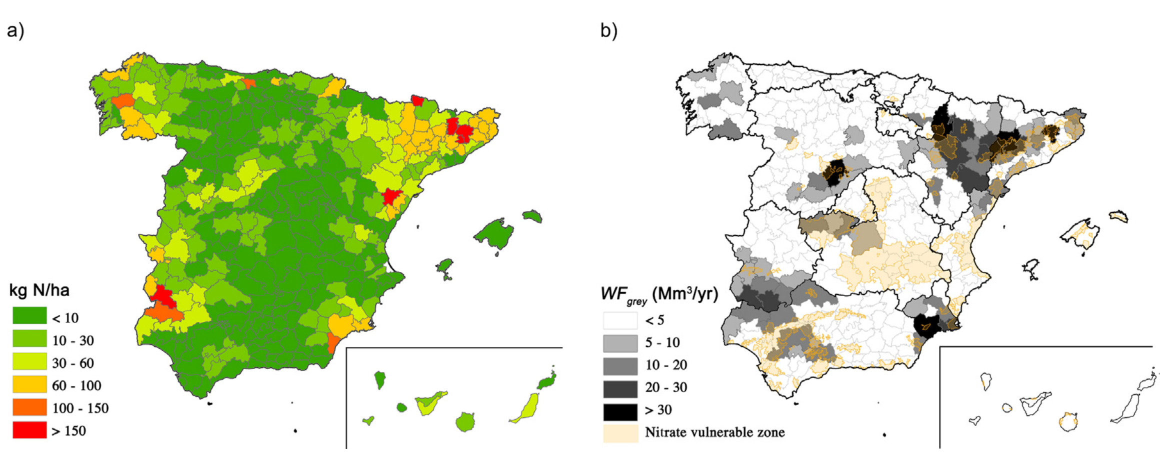

Fig. 5. (a) Nitrogen excreted per hectare of agrarian surface at the agricultural district level and (b) the grey WF from pig slurry used as a fertiliser.

the national livestock policy, taking into account the connection between agriculture and livestock and setting clear boundaries in order to minimise geographical concentration, especially in the case of industrial systems.

4.2. The environmental sustainability of the water footprint of Spanish pork

With indicators such as monthly BWS and WPL, it has been possible to identify unsustainable elements in the Spanish pork supply chain. Performing the analysis on a basin scale provides more realistic information than is done at the country level, especially in large countries (Hoekstra et al., 2011).

Our method of measuring the WF of livestock products in terms of water volumes consumed or polluted is in line with the WFN method as applied for example by Mekonnen and Hoekstra (2012), but differs from Ridoutt et al. (2010), who multiply water volumes with a water stress index (WSI) taken from Pfister et al. (2009). The WSI is used to normalise blue WF values to express the impact of water consumption and enable comparison between different products. Zonderland-Thomassen and Ledgard (2012) estimated the WF of New Zealand dairy farming using the two different approaches and show that the methods are similar in terms of accounting. The do differ in how they estimate the sustainability of water use (by comparing to BWS in the WFN method) or the impact of water use (by multiplying to WSI in the Pfister-method). In the end, however, results are quite similar from a qualitative point of view: hotspots occur where both water consumption and water scarcity or stress is high (Jefferies et al., 2012).

The incorporation of the grey WF as an indicator of degradative water use improves the environmental sustainability assessment developed by other authors, who mostly focused exclusively on the blue and green WF, which shows consumptive water use (Van Oel et al., 2009; Aldaya and Hoekstra, 2010). The grey WF assessment in this study was limited to nitrogen, thus considering partially the issue of eutrophication. The inclusion of phosphorus in the grey WF assesment, or the use of other indicators to cover issues such as aquatic acidification or ecotoxicity from pesticides or metals could complete the water quality impact assesment (Kounina et al., 2013). Even so, the use of the WPL at river basin scale allows us to enhance the volumetric approach towards an indicator of degradative water use (Zonderland-Thomassen and Ledgard, 2012).

The use of a green water scarcity index as proposed by Hoekstra et al. (2011), or the comparison of the green WF under crop production with the green water consumed by natural or anthropogenic reference land use, as proposed by Canals et al. (2009), could provide useful information to better understand the environmental consequences of the green WF. As pointed out by several authors (Pfister and Hellweg, 2009; Ridoutt and Pfister, 2010; Hoekstra, 2013), the use of green water resources is strongly linked to land use, so the scarcity of green water resources coincides with the scarcity of suitable land for rain-fed agriculture. The green WF is particularly interesting from a water allocation and water productivity point of view: since animal products have a much greater green WF per kcal than nutritionally equivalent crop products, greater nutritional water productivity is obtained when water is allocated to the latter (Hoekstra, 2014). This is especially true in the case of pigs, since off-farm feedstuffs represent most of the nutritional requirements.

4.3. Water footprint of industrial versus extensive systems

As other authors have reported, animals raised in extensive systems often have a larger WF than those raised in industrial ones (Mekonnen and Hoekstra, 2012; Gerbens-Leenes et al., 2013). The reason is that the FCR is generally higher in industrial systems, because animals are raised under confined and controlled conditions, which implies limited freedom of movement, so that most calories are used for fattening. Thus the energy consumption of a free-ranging pig is around 50% of daily feed intake, while it is 10–30% for indoors pigs (Rodriguez-Estevez et al., 2010; Moehn et al., 2013). Other influencing factors are weight, age at slaughter and animal breed. Industrial systems are commonly based on highly productive pig breeds, generally lighter and younger when slaughtered, while extensive farms, using Iberian pigs, favour carcass quality over quantity. Finally, the relatively high FCR in industrial systems is partly achieved trough high-quality feed. The disadvantage of the concentrate feed is that it has a larger WF per kg than the feed obtained through foraging. Therefore, the advantage of smaller feed volumes in industrial pig farming is partly offset by the larger WF of the feed per kg.

The WF of livestock is strongly influenced by the place and system of production (Ridoutt et al., 2012). Gerbens-Leenes et al. (2013) found that the WF of pork varies widely across countries because of the large differences in the composition of pig feed, making it difficult to draw general conclusions regarding industrial versus extensive systems. Unlike other livestock managed as free-range in Spain, such as cows, sheep or goats, pigs require large amounts of feed from outside the grazing system, with resultant freshwater use associated with the production of concentrated feed.

It should be noted that a large WF is not always linked to a greater environmental impact. For instance, the green water consumed by crops is, to some extent, related to fertiliser application, tillage or ecosystem transformation. In contrast, *dehesa* systems are characterised by low anthropogenic pressure and high biodiversity and landscape values (Moreno and Pulido, 2009). In addition, in our analysis we have not considered other *dehesa* services, such as habitat conservation, carbon sequestration and fire prevention or animal welfare. A comprehensive analysis, which includes other environmental aspects and indicators, will be required to obtain the complete picture.

4.4. Data limitation

Several uncertainties in this research such as feed composition or the WF values may limit the accuracy of the results. For instance, the WF values of crops can contain an uncertainty factor of ±20–30% (Zhuo et al., 2014). The source of feed is another relevant issue, since the WF of feed varies significantly according to its origin. The use of the DATACOMEX dataset (MITC, 2011) limits the uncertainties derived from triangular operations, because goods are accounted for from the real source and not from intermediate provenance. The application of multi-regional environmental extended input–output databases, such as EXIOPOL, EORA or WIOD, could improve the accuracy of the baseline information, as it would enable us to disaggregate the information at micro (company) or meso (sector) level and allow us to capture the re-exports (Tukker et al., 2009; Feng et al., 2011; Tukker and Dietzenbacher, 2013). Nonetheless, the utilisation of trade data at country level rather than regional or watershed level still represents a major limitation for the WF analyses.

The grey WF analysis in this study focused on the pollution from nitrogen fertilizers applied in feed crop cultivation; the effect of other compounds, such as phosphorous and pesticides, has not been included. Also we have not studied water pollution from the use of metals and antibiotics commonly used in livestock production. The values taken for C_{nat} and C_{max} are other important uncertainty factors in the grey WF. We have used a constant value for C_{nat} of 0.5 mg/L of nitrogen as proposed by Liu et al. (2012) and the maximum European allowed concentration (50 mg/L of nitrate) for C_{max}, rather than other more restrictive water quality standards proposed by other authors (Frank et al., 2013). In doing so we may have overestimated the assimilative capacity of the ecosystem.

Other major uncertainties, relating mainly to the WF assessment for extensive management, are: (i) we assumed that the composition of concentrate for extensive systems is the same as for industrial ones; (ii) acorn yields are extremely variable (Moreno and Pulido, 2009); (iii) all the water taken up by forests is distributed in secondary products (acorn, wood or cork), regardless of the water used for other environmental services; and (iv) applying a constant nitrogen application rate may prove prejudicial for extensive systems, where land availability is usually greater.

5. Conclusions

The substantial growth in the Spanish pork sector in recent years, particularly focused on meat and live animal exports, has led to a major increase in the WF, which is associated not only with direct water requirements and pollution, but also with indirect water consumption and pollution to produce feed. The need for substantial feed crop imports has resulted in pronounced foreign dependency. Therefore, a significant portion of the environmental impacts caused by the feed production chain is externalised to other countries, while this saves the amount of water required to produce these commodities in Spain.

Comparing the WF of feed with indicators of water scarcity or water pollution is a feasible option to identify the sector's environmental sustainability. Even though half the WF of feed production for the Spanish swine sector is in other countries, the greatest problems relating to blue water consumption were identified in Spanish watersheds. Furthermore, the geographical concentration of industrial pig farms in Spain puts local water resources under stress, specifically through freshwater pollution from excessive manure. Including the grey WF analysis for pig slurry management provides a comprehensive view of these impacts.

Although Iberian pig production plays a crucial role in Spain, most of these pigs are raised industrially. Raising pigs in extensive farming results in a larger overall WF per tonne of meat, but – due to lower stocking densities – a smaller WF per hectare.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2015.05.023

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